

****FULL TITLE****

*ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION***

****NAMES OF EDITORS****

On the Luminosity and Mass Loss of Galactic AGB Stars

R. Guandalini, M. Busso and M. Cardinali

Dipartimento di Fisica, Università di Perugia, Perugia, Italy

Abstract. As part of a reanalysis of Galactic Asymptotic Giant Branch stars (hereafter AGB stars) at infrared wavelengths, we discuss here two samples (the first of carbon-rich stars, the second of S stars) for which photometry in the near- and mid-IR and distance estimates are available. Whenever possible we searched also for mass-loss rates. The observed spectral energy distributions extended in all cases up to 20 μm and for the best-observed sources up to 45 μm . The wide wavelength coverage allows us to obtain reliable bolometric corrections, and hence bolometric magnitudes. We show that mid-IR fluxes are crucial for estimating bolometric magnitudes for stars with dusty envelopes and that the so-called luminosity problem of C stars (i.e. the suggestion that they are less luminous than predicted by models) does not appear to exist.

1. Introduction

The Asymptotic Giant Branch phase (see e.g. Busso, Gallino, & Wasserburg 1999) terminates the evolution of stars with low and intermediate mass (all those with $M \leq 7-8 M_{\odot}$), by strong phenomena of mass loss thanks to stellar winds powered by radiation pressure on dust grains (Habing 1996). After this stage, they generate planetary nebulae and start a blueward path, which ultimately gives birth to a white dwarf (Herwig 2005).

One fundamental characteristic of AGB stars is that they replenish the interstellar medium with about 70% of all the matter returned after stellar evolution (Sedlmayr 1994); this is done through the formation of extended circumstellar envelopes (Winters et al. 2002). As AGB stars radiate most of their flux at long wavelengths, large surveys of infrared (IR) observations play a fundamental role in studying their luminosity and mass loss (see e.g. Habing 1996; Epchtein 1999); unfortunately, until recently the bolometric magnitudes of evolved AGB stars have been poorly known, due to insufficient coverage of the IR range and to difficulties in measuring the distances of these stars.

Another big problem that is still open is the history of mass loss, whose efficiency controls the duration of the AGB phase and the amount of matter returned to the interstellar medium. This prevents a quantitative assessment of the total yield of newly produced nuclei and sheds doubts on the actual mass involved in obscured circumstellar envelopes.

Quite recently, the availability of large IR databases from space-borne telescopes and the increased amount of ground-based mid-IR observations has substantially improved the situation (see e.g. Guandalini et al. 2006, and references therein). At the same time, Hipparcos distances for AGB stars have been corrected for various biases (see Bergeat & Chevallier 2005; Whitelock et al. 2006,

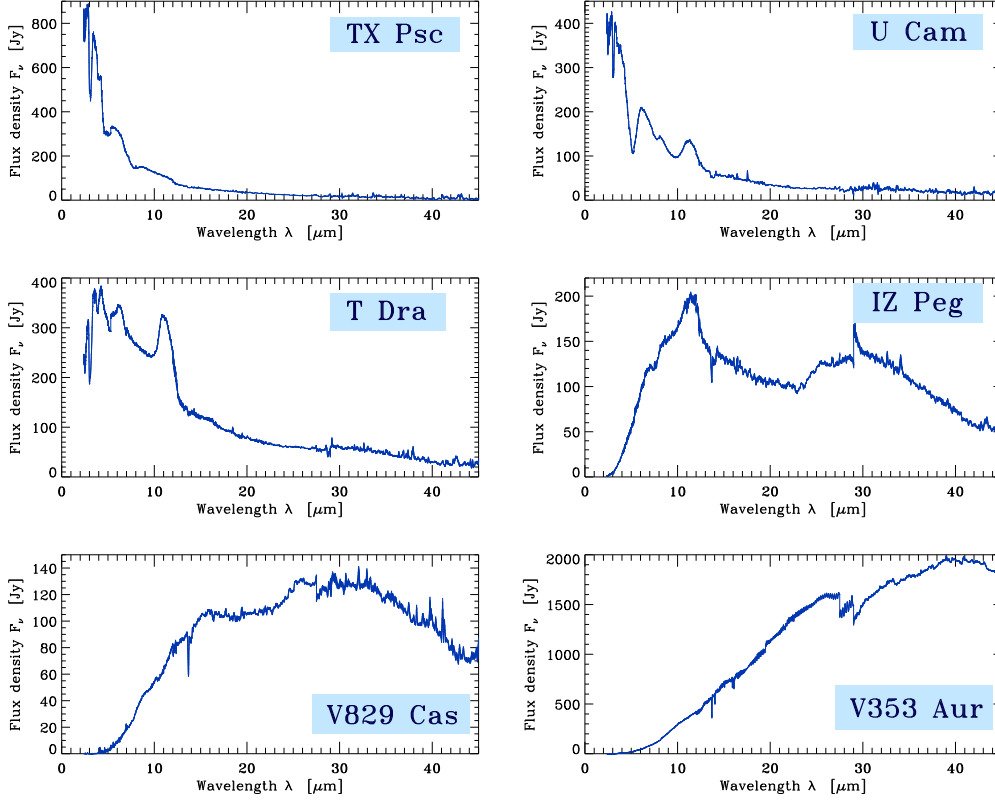


Figure 1. ISO-SWS spectra for an irregular variable (TX Psc), a semiregular variable (U Cam), two Mira variables (T Dra and IZ Peg), and two post-AGB stars (V829 Cas and V353 Aur). The dominant role of IR emission longward of $20\ \mu\text{m}$ for Miras and post-AGB sources seems to be a general property for C-rich AGB stars.

and references therein), so that the study of luminosities, colors and mass loss can now be performed in a more quantitative way.

In this paper we present the current status of our research on two samples (the first of carbon-rich stars, the second of S stars), for which photometry in the near- and mid-IR as well as distance estimates are available. In particular, we show our estimates of the bolometric magnitudes of these stars.

2. Discussion

Here we present some results from an analysis of two samples of AGB stars. The sample of C stars is fully described in Guandalini et al. (2006), while the sample of S stars, made of more than 600 sources, is studied in detail in Guandalini et al. (2007), and here we show its first preliminary results.

For both samples we have collected photometric data in near- and mid-IR filters from the catalogues of ground-based observations 2MASS and DENIS and from the databases of two space-borne observatories, ISO (Infrared Space

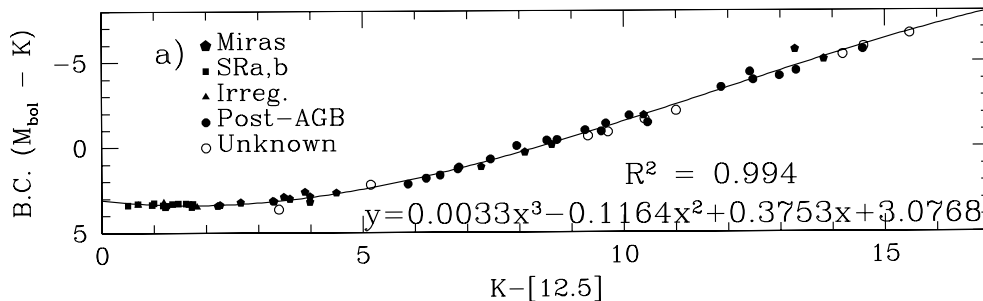


Figure 2. Bolometric corrections for the K magnitude as a function of the $K-[12.5]$ color. They were derived for AGB C stars with complete SEDs, from 2MASS and ISO-SWS, up to $45 \mu\text{m}$ (Guandalini et al. 2006).

Observatory) and MSX (Midcourse Space eXperiment). A detailed presentation of the methods used in our analysis can be found in Guandalini et al. (2006).

Figure 1 shows a gradual changes from semiregulars to Miras and then to post-AGB stars in the effective wavelengths at which maximum emission occurs. Thus, evolved AGB C-rich stars (Mira and post-AGB) emit a large part of their flux at mid-IR wavelengths (in particular for the region $> 15 \mu\text{m}$). Therefore, an extended wavelength coverage is fundamental in the study of the final evolutionary phases of stars of low and intermediate mass; in fact, it allows us to obtain reliable bolometric corrections and trustworthy estimates of luminosity. Mid-IR fluxes are crucial for estimating the bolometric magnitudes of stars with dusty envelopes.

In Figure 2 we show the bolometric correction obtained from our analysis of the C-rich stars. Optically-selected sources (in general semiregular variables) have small corrections: their flux is well estimated from traditional criteria at shorter wavelengths, as most flux is radiated in near-IR. On the other hand, AGB stars with significant IR excess present larger corrections: criteria that also include mid-IR wavelengths are needed to obtain reliable estimates of their total flux.

Figure 3 presents two bolometric corrections that we have found through an analysis of an S star sample with techniques similar to those used for C-rich sources. They are both well-determined and show the importance of mid-IR observations (magnitudes in the $[8.8]$ and $[12.5]$ bands) for S stars. More details are discussed in Guandalini et al. (2007).

Figure 4 (right panel) shows that the luminosity function of Galactic C-rich stars is continuous, unique and quite wide. We found it to be in good agreement with the luminosities of AGB models with minimal or no overshoot (Straniero et al. 2003).

The left panel of Figure 4 presents the luminosity function of Galactic S-MS-SC stars obtained with the same methods as used for C stars (right panel). Our global distribution for this sample is also continuous, unique and in good agreement with model predictions (Straniero et al. 2003). The analysis of the luminosity of S stars is fully described in Guandalini et al. (2007).

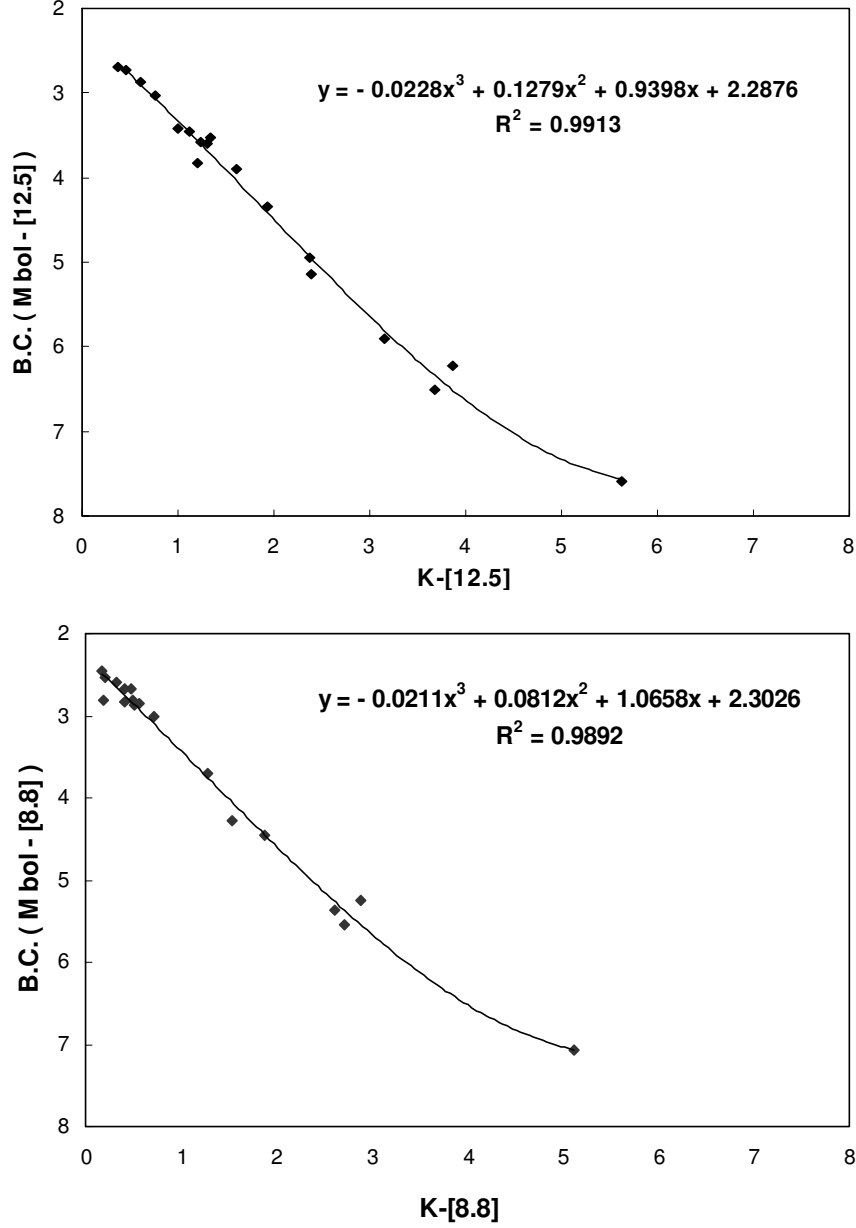


Figure 3. Formulation of two bolometric corrections obtained from a sample of S stars for the [12.5] magnitude as a function of the $K-[12.5]$ color (*upper panel*) and for the [8.8] magnitude as a function of the $K-[8.8]$ color (*lower panel*). They were derived for AGB S stars with complete SEDs, from 2MASS and ISO-SWS, up to $45\ \mu\text{m}$.

Finally, there is no clear correlation between mass loss estimates (obtained from radio observations) and bolometric magnitudes for the sample of C stars. Indeed, there seem to be different relations for different variability types. Very

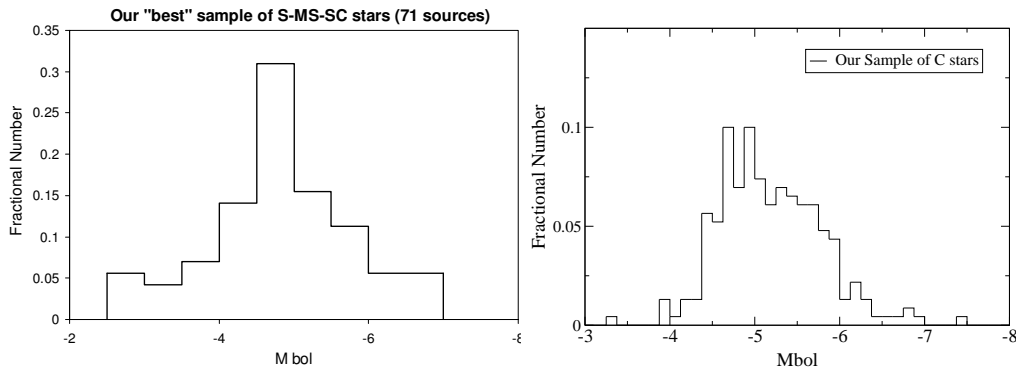


Figure 4. *Left*: histogram showing the fractional number of Galactic S stars per magnitude interval (71 sources). *Right*: same for the sample of Galactic C stars (230 sources).

likely, several parameters affect the order of magnitude of mass loss rates during AGB evolution (Guandalini et al. 2006, see Fig. 11 and the corresponding text).

3. Conclusions

Our estimates of bolometric magnitude for Galactic AGB C-rich and S stars are in agreement with theoretical models based on the Schwarzschild criteria for convection, with no evidence for underluminous carbon stars. In obtaining this result, wide coverage of the spectral energy distribution at mid-IR wavelengths plays a crucial role. We found no clear correlation between mass loss and bolometric magnitude and conclude that other physical parameters and also different mass loss mechanisms must be involved.

References

- Bergeat, J. & Chevallier, L. 2005, *A&A*, 429, 235
- Busso, M., Gallino, R., & Wasserburg, G. J. 1999, *ARA&A*, 37, 239
- Epchtein, N. 1999, in *IAU Symp. 191: Asymptotic Giant Branch Stars*, ed. T. Le Bertre, A. Lèbre, & C. Waelkens (ASP), p. 97
- Guandalini, R., Busso, M., Ciprini, S., Silvestro, G., & Persi, P. 2006, *A&A*, 445, 1069
- Guandalini, R., Busso, M., & Cardinali, M. 2007, in preparation
- Habing, H. J. 1996, *A&AR*, 7, 97
- Herwig, F. 2005, *ARA&A*, 43, 435
- Sedlmayr, E. 1994, in *IAU Coll. 146: Molecules in the Stellar Environment*, ed. U. G. Jørgensen (Springer), Lecture Notes in Physics, 428, 163
- Straniero, O., Domínguez, I., Cristallo, S., & Gallino, R. 2003, *PASA*, 20, 389
- Whitelock, P. A., Feast, M. W., Marang, F., & Groenewegen, M. A. T. 2006, *MNRAS*, 369, 751
- Winters, J. M., Le Bertre, T., Nyman, L.-Å., Omont, A., & Jeong, K. S. 2002, *A&A*, 388, 609

Discussion

Feast: I would like to caution that for Miras, at least, most of the Hipparcos parallaxes have large uncertainties and thus selection effects can lead to large and very uncertain statistical corrections (see MNRAS 369, 751, 2006, § 9).

Guandalini: I agree that Hipparcos parallaxes of variable stars have large uncertainties. However, we are trying to find corrections to the recognized uncertainties; moreover, Hipparcos measurements are often the best estimate (sometimes the only one) of distance for AGB stars (semiregular variables in particular). We are using the data that we can find in the literature and we are aware of the problems linked to them. These uncertain estimates are better than no estimates at all.

Willson: A comment: Not knowing the mass, empirical fits to \dot{M} vs $\log L$ take parallel, steep lines into a single, shallow slope. A question: How big are the uncertainties in your M_{bol} ?

Guandalini: I fully agree with the comment regarding the importance of the mass of AGB stars. The uncertainties of our estimates of M_{bol} arise from many parameters; however, the distances are the main source of uncertainty. The uncertainties of our bolometric magnitudes vary from star to star, but they are < 0.5 mag.